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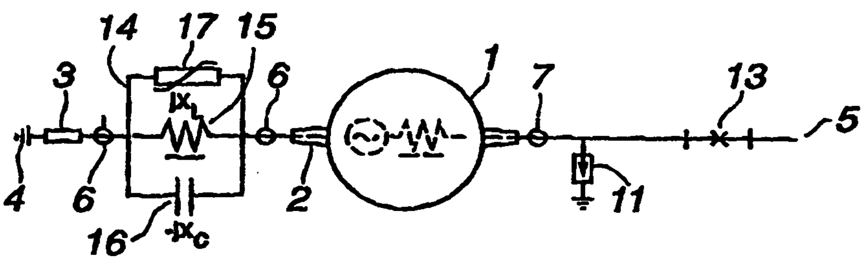

(57) Abstract

Connection arrangements for reducing the effect of third-harmonic voltages in case of direct connection of AC machines (1) to a three-phase distribution or transmission network (5), wherein the stator winding of the AC machine is Y-connected and wherein the neutral point of the winding (2) is available, comprising a suppression filter (14) tuned to the third harmonic, with an overvoltage protection device (17) arranged between the neutral point (2) and ground of the power network (4).

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Reduction of harmonics in AC machines

TECHNICAL FIELD

A voltage of a frequency three times the frequency of the network, referred to below as the third harmonic, is generated in different ways in distribution and transmission networks, commonly referred to below as power networks. This voltage generates a third-harmonic current which often causes great problems, on the one hand for apparatus and attachments connected to the power network, and on the other hand for the third-harmonic generating devices themselves. The third-harmonic problems are often directly associated with the way the connected devices are grounded. Because there are several different principles and regulations for grounding in power networks it follows that the methods for reducing influence from third harmonics can be extremely different. The present invention deals with how to reduce the problems with third-harmonic currents that may arise during generator and motor operation of AC machines. The invention consists of a method and a connection arrangement for achieving the above mentioned.

BACKGROUND ART, THE PROBLEM

When calculating and designing three-phase AC machines, the aim is normally to achieve as symmetrical and sinusoidal quantities as possible. With respect to terminals the stator windings of the above-mentioned machines may, when being manufactured, be connected in many different ways. For some machines the stator windings are connected in Δ, for others in Y-connection, where the so-called neutral point sometimes is not drawn out from the machine. For the machines concerned in this invention the three-phase winding is Y-connected and all of the winding ends including the neutral point are drawn out from the machine. In order to obtain an economic yield from the electromagnetic circuit in common types of AC machines, a third-harmonic EMF is generated as a harmonic to the fundamental EMF.

It is well known that the chording of the stator winding may be chosen in order to eliminate one or more of the harmonics. It is also well

known regarding synchronous AC machines with salient poles that, in addition, the shape of the EMF of these machines may be influenced and improved by choosing the design of the rotor poles and, especially, the shape of the pole shoes in an appropriate way.

A total elimination of the third harmonic of the voltage by choosing an appropriate size for the winding step however means a considerable reduction, approximately 14%, of the fundamental frequency voltage available for torque generation. This thus means only 86% utilization of the possible rated power. In order to avoid this reduction, the winding step is used mainly for suppression of the fifth harmonic whereby the reduction becomes only a few percent. Adaptation of the shape of the pole shoe is often used for a cost-effective reduction of the seventh harmonic voltage. Elimination or reduction of the harmful effects of the third-harmonic voltage/current must thus be performed by different methods.

When a generator is to be connected directly to an existing power network the grounding of the generator cannot normally be freely chosen due to the fact that this is mainly determined by the grounding method of the existing power network. Concerning grounding, however, there are important criteria which should be fulfilled, namely:

- the power network may be directly grounded, resonance-grounded, ungrounded, high-impedance grounded

- a third-harmonic current through the generator as well as other equipment connected in the power network must for many reasons be limited

If the neutral point is connected to the ground of the power network by a relatively high-ohmic impedance for both the fundamental and the third component, increased voltages relative to ground will arise on the unfaulted phases in case of a ground fault. This cannot be accepted on certain markets.

By connecting the neutral point directly, or via an appropriate impedance, to the ground of the power network, this will however allow the AC machine concerned to contribute to obtain appropriate magnitudes of the zero-sequence impedances to be able to handle the fault conditions, for example voltage increases on unfaulted phases, which may arise in the electrical system.

Traditionally, certain criteria should be fulfilled concerning the zero-sequence impedance R_0+jX_0 and positive-sequence reactance X_+ of the systems. These criteria are often denoted as the following inequalities and state that

$X_0/X_+<3$ and $R_0/X_+<1$

In other respects, these inequalities can be interpreted in such a way that in case of a ground fault in one phase, the voltage increase, in the unfaulted phases relative to ground, can be limited to 80%, which is an economical value from the point of view of insulation coordination, of what would have occurred if X_0 and/or $R_0 \rightarrow \infty$.

The disadvantage with a direct connection of the neutral point to the ground of the power network is that, if the voltages contain a third harmonic, a third-harmonic current will start to flow in the phase conductors which closes its circuit through the ground and/or the neutral conductors. It can be mentioned that there are no regulations prohibiting such an arrangement and that there are such installations in operation.

Concerning low-voltage power networks, there are today in most networks third-harmonic currents which close their circuit through the neutral conductor and cause thermal as well as acoustic problems. The occurrence of and a method of reducing the influence of these third-harmonic currents will be described below.

When it comes to limiting the detrimental effect of the third-harmonic voltage and the third-harmonic current, there are a number of different

methods in addition to grounding of the neutral point by means of appropriate impedances.

A relatively common method of grounding is to connect a high-ohmic resistance to a point on the power network which is always connected. This can be done by means of a Z/0-connected transformer connected to the network. To obtain the required selective ground fault protection devices, however, the resistance should be dimensioned such that at least 15 A ground fault current at full neutral point voltage is obtained.

Another common method for handling the third-harmonic problems for generator plants where the neutral point is available and which, in addition has obvious advantages with regard to limiting fault current in case of a ground fault in the generator appears from the accompanying figure 1. A generator 1 has the neutral point 2 via an impedance 3, often a neutral-point resistor dimensioned for ground fault current of some harmless 10-20 amperes or so, connected to the ground of the power network 4. A ground fault in the generator thus can cause a ground-fault current via the impedance, and by controlling the ground fault current, measures can be taken to disconnect the generator or a possible defective phase. The phase voltages of the generator are connected to a Δ/Y-0 connected so-called step-up transformer 3 which has to be dimensioned for full power even if it should not be reason to change the voltage level. A ground fault in the Δ-winding of the transformer is limited, in the same way as for a ground fault in the windings of the generator, to some 10-20 amperes. The third-harmonic voltages with which the generator is afflicted could give a third-harmonic current. However, the third-harmonic voltage is superimposed on the phase voltages of the Æ-winding but cannot generate any third-harmonic current via the neutral-point resistance to ground. This means that, on the Y-side of the transformer, i.e. on the power network side, no third-harmonic current is sensed. In figure 1 the necessary auxiliary power input from the network and the field excitation of the generator are omitted. As is otherwise clear from the figure, current measurement devices 6 and 7 are needed for the ground fault current and for the current delivered from the generator. On the generator side, in addition, both a disconnector

and a circuit breaker 8 are needed. For the step-up transformer both current measurement 9 and 10 are needed for incoming and outgoing currents. In addition at the input side of the step-up transformer an overvoltage protection device 11 is needed. The network side is then grounded in a normal way via the neutral point of the Y-side. Also here a current measurement device 12 is needed. On the network side both a disconnector and a circuit breaker 13 are then needed as usual.

The EPRI report EL-3391 "High Voltage Stator Winding Development" describes in Section 4 the interplay with the power network in case of direct connection of superconducting high-voltage generators. 4.1 describes the preferred embodiment, in this publication, of Δ-connected generators, whereby the third-harmonic problems in the power network disappear through the currents circulating in Δ. 4.1.1 and 4.1.2 describe grounding methods. The low zero-sequence impedance is ensured via a shunt-connected transformer.

From what is stated above it is obvious that concerning Y-connected direct-connected high-voltage electric machines, the question of third harmonics is a problem which is not satisfactorily solved.

As mentioned above, low-voltage distribution networks contain an obvious third-harmonic current which is difficult to remedy. This is due to the fact that modern fluorescent lamp fittings, thyristor controllers and power supply units chop or load the line voltage non-linearly. These disturbances influence other apparatus, cause power losses and may affect persons hypersensitive to electricity. The disturbances have an obvious third-harmonic nature. In order to reduce the disturbances there is a filter which is described in ERA 8:1994, page 26, and which is installed into the neutral conductor and means that the effect of the harmful third harmonic disturbances can be drastically reduced.

SUMMARY OF THE INVENTION, ADVANTAGES

To be able to cope with the problems which arise from third-harmonic voltages in case of direct connection of AC machines to a three-phase power network, i.e. when there is no transformer between the AC machine

and the three-phase network, according to the invention a special method is used and a connection arrangement, which comprises connecting a suppression filter tuned to the third harmonic between the neutral point in the Y-connected AC machine and the ground of the power network, possibly via a very low-ohmic resistor. The filter comprises a parallel resonance circuit which consists of a reactor with the fundamental reactance X_L connected in parallel with a capacitive reactance with a fundamental value $-jX_C$. The ratio between the reactances to achieve third-harmonic parallel resonance will thus be

$$3\ X_L = X_C/3$$

To limit the voltage across the filter to economic values a conventional overvoltage protection device is included, as an integral part of the filter, and is connected across the parallel resonance circuit. An overvoltage protection device connected in this way also limits the voltage at the neutral point to such values that a tapered insulation can be utilized in the stator winding. This is important especially in very high-voltage AC machines.

The dimensioning of the filter and its overvoltage protection device shall be such that the parallel circuit is capable, during normal operation, of linearly absorbing the third-harmonic voltage from the AC machine. In the event of a fault the overvoltage protection device is to limit the fault voltage so that the fault current is allowed to flow through the overvoltage protection device if the fault is considerable.

There are a number of considerable advantages with an arrangement according to the invention. As is clear, among other things, from the accompanying figure 2, which shows an embodiment of the invention, the step-up transformer as well as the associated current measurement devices and circuit-breakers and disconnectors are eliminated.

Because the filter will only be loaded by zero-sequence quantities and even if there will occur a large circulating third-harmonic resonant current, the rated power of the filter will be essentially lower than the rated power of the step-up transformer. This means that a solution

to the third-harmonic problems according to the invention will be considerably less cost-demanding than a solution according to the prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an example of how to proceed, according to prior art, in order to deal with the third-harmonic problems of AC machines which are connected to a three-phase power network. The solution comprises use of a step-up transformer connected in Δ/Y-0.

Figure 2 shows how the third-harmonic problems is coped with according to the invention with the aid of a third-harmonic suppression filter between the neutral point of the AC machine and the ground of the power network.

Figures 3 and 4 show alternative embodiments of a third-harmonic suppression filter according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

One embodiment of the invention is clear from figure 2. The reference numbers 1, 2, 3, 4, 5, 6, 7, 11 and 13 refer to the corresponding numbers according to figure 1. Figure 2 also shows the integrated filter 14 with a parallel resonance circuit comprising a reactor 14 in parallel with a capacitance 16 and across which circuit an overvoltage protection device is connected.

Because the filter, in principle, is to absorb a voltage without the reactor reaching saturation, it is essential that the third-harmonic tuning is accurately done and remains stable. With a conventional reactor it may in certain cases be difficult to achieve the sufficient and desired accuracy. Within the scope of the invention there are, therefore, also embodiments which ensure that the suppression frequency of the filter will be three times the actual frequency of the network.

Such an embodiment is clear from figure 3. Here a reactor 18 is used which is designed as an electronically controllable reactor with control windings 19. Such a reactor is among other things known from an article "A test installation of a self-tuned ac filter in the Konti-Skan 2 HVDC link", published at IEEE/KTH Stockholm Power Tech Conference, Stockholm, June 18-22, 1995. With such a reactor the resonance frequency can be maintained even at minor faults in the capacitor part of the filter and become independent of variations in temperature etc. Using a controllable reactor, however, means that the filter must comprise some kind of measurement of the network frequency or, alternatively, the third-harmonic frequency and a control circuit which, via its executive device and the control winding, ensure that the suppression frequency of the resonance circuit corresponds to the third harmonic.

Another embodiment which ensures a correct suppression frequency is clear from figure 4. Here, a voltage source 20 is introduced in the reactor branch of the suppression filter, which voltage source with aid of a controller 21 generates a control voltage. Current through a reactor always means a certain ohmic voltage drop. By measuring the current I in the reactor branch, with knowledge of the resistance of the reactor, the controller can be programmed so that the control voltage compensates for the ohmic voltage drop of the reactor. By measuring the mains frequency f, the controller can be programmed so that the control voltage will be such that the suppression frequency of the filter corresponds to the third harmonic. The required control power is provided, via the controller, from the network.

CLAIMS

1. A method for reducing the effect of third-harmonic voltages in case of direct connection of AC machines (1) to a three-phase distribution or transmission network (5), wherein the stator winding of the AC machine is Y-connected and wherein the neutral point of the winding (2) is available, which method is **characterized** in that a suppression filter (14), tuned to the third harmonic, with an overvoltage protection device (17) is connected between the neutral point and ground of the distribution or transmission network (4).

2. A connection arrangement for carrying out the method according to claim 1 for reducing the effect of third-harmonic voltages in case of direct connection of AC machines (1) to a three-phase distribution or transmission network (5), wherein the stator winding of the AC machine is Y-connected and wherein the neutral point of the winding (2) is available, **characterized** in that a suppression filter (14), tuned to the third harmonic, with an overvoltage protection device (17) is arranged between the neutral point (2) and ground of the distribution or transmission network (4).

3. A connection arrangement according to claim 2, **characterized** in that the suppression filter tuned to the third harmonic comprises a parallel resonance circuit consisting of a reactor (15) connected in parallel with a capacitive reactance (16) and that, in parallel with the parallel resonance circuit, an overvoltage protection device (17) is connected.

4. A connection arrangement according to claims 2 and 3, **characterized** in that the reactor is designed as a controllable reactor (18) which, via a control winding (19), affects the frequency of the suppression filter tuned to the third harmonic to correspond three times the actual frequency of the network.

5. A connection arrangement according to claims 2 and 3, **characteriz d** in that, in series to the reactor (15) in the reactor branch of the filter, a control voltage (20) is connected which is

controlled by a controller (21) so that the control voltage compensates the ohmic voltage drop of the reactor and/or affects the suppression filter tuned to the third harmonic to correspond three times the actual frequency of the network.

6. A connection arrangement according to claim 2, **characterized** in that a low-ohmic resistor (3) is arranged between ground of the distribution or transmission network (4) and the suppression filter (14) tuned to the third harmonic.

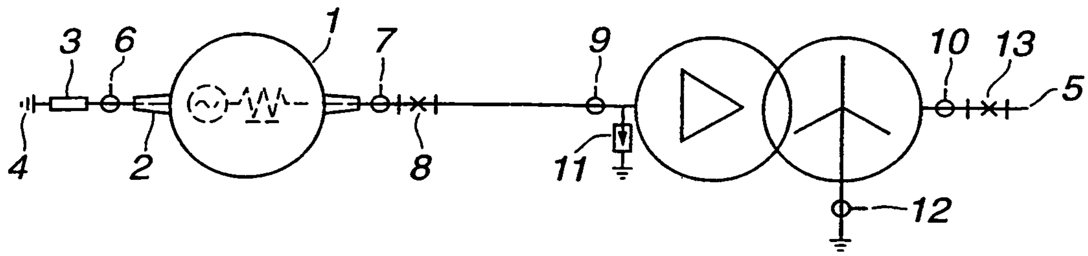

Fig. 1

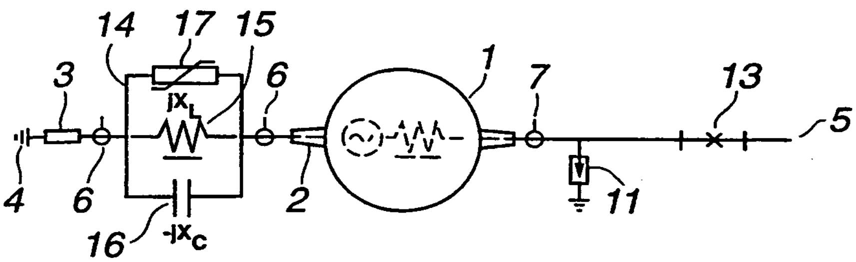

Fig. 2

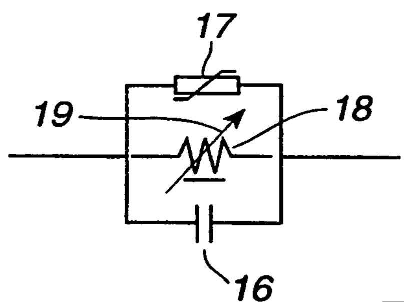

Fig. 3

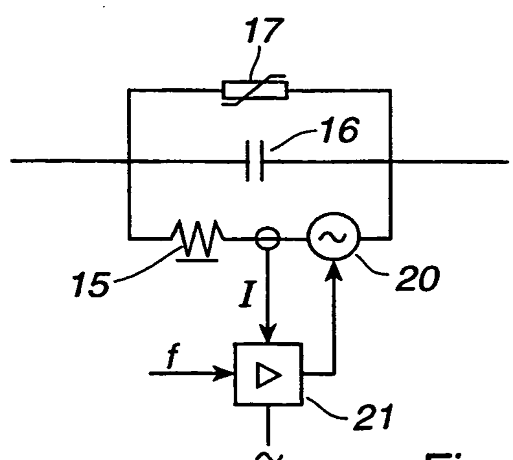

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00876

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02J 3/01
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4551780 A (M. CANAY), 5 November 1985 (05.11.85), abstract --	1-6
A	US 4308575 A (AKIRA MASE), 29 December 1981 (29.12.81), abstract --	1-6
A	US 2241832 A (H.W. WAHLQUIST), 13 May 1941 (13.05.41), page 2, column 2, line 14 - page 4, column 2, line 8 -- --------	1-6

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

01/09/97

International application No.
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